RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)									DATE February 2000
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense Wide/BA 2							R-1 ITEM NOMENCLATURE Lincoln Laboratory PE 0602234D8Z		
COST *(In Millions)*	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	Cost to Complete	Total Cost
Total Program Element (PE) Cost	20.219	20.189	18.602	18.845	21.089	21.569	22.345	Continuing	Continuing
Lincoln Laboratory/P534	20.219	20.189	18.602	18.845	21.089	21.569	22.345	Continuing	Continuing

(U) **A. Mission Description and Budget Item Justification**

(U) **BRIEF DESCRIPTION OF ELEMENT**

(U)The Lincoln Laboratory (LL) program is a high technology research and development effort conducted through a cost reimbursable contract with the Massachusetts Institute of Technology (MIT). LL is operated as a FFRDC administered by the DoD, and is unique among DoD FFRDCs. It has no funding sources other than the Line for its innovative research and development efforts. This is due to the fact that LL is operated by MIT at no fee and may not charge for IR&D (under A-21). Other DoD FFRDCs do charge a fee with which they may support research efforts.
(U)The LL Line funds research activities that directly lead to the development of new system concepts, new technologies, and new components and materials. Historically, the Line funding supported many development and demonstration programs which have led to such significant DoD systems as JSTARS, MILSTAR, GEODSS, as well as to solid-state devices and processes of major importance to the military industrial base. In addition to being the foundation for many new LL programs, the Line also supports other ongoing Laboratory programs with state-of-the-art technology developments. The program has the following 4 research elements:

- Target surveillance and recognition, with emphasis on (1) revolutionary sensing techniques and algorithms for detecting and recognizing battlefield targets both in the clear and in difficult deployments, (2) supporting data collection and phenomenology, (3) fundamental target-recognition bounds and their implications for sensor and algorithm design, and (4) revolutionary new approaches for automated passive sonar target classification of submarine targets and discrimination of submarines from surface ship clutter.
- High-connectivity, low-cost military global defense network and communications systems, with emphasis on new antennas, RF technology, network protocols (including for mobile users with lightweight transceivers), high-rate fiber and free-space optical communications systems, and the interconnection of these very disparate modalities into a global defense network that can truly realize the vision of a \`from sensor to shooter\` communications infrastructure which will greatly enhance force effectiveness by providing the right information at the right time anywhere in the world;

- Advanced combat support technologies for active hyperspectral sensing systems and compact biological agent detection systems. The focus in biological agent detection is in developing technology for compact, lightweight, real-time biological-agent sensors with extremely high sensitivity (<1 agent containing particle per liter of air) and with strong background clutter rejection for extremely low false-alarm are (<1 per week). The primary objective for the active hyperspectral sensing system development is to demonstrate the feasibility and utility of combining active illumination with hyperspectral imaging for a range of military application including CID.
- Revolutionary, advanced electronic/optical technology, with specific emphasis on optical sampling for direct analog-to-digital conversion on the microwave carrier in digital receivers for radar and electronic intercept, 3-D imaging and high sensitivity IR focal-plane arrays for advanced missile seekers, mid-infrared semiconductor lasers to counter advanced heat-seeking missiles, new miniature fluorescent and microfluidic sensors for rapidly detecting and identifying low concentrations of biowarfare agents, solid state low-light imagers for improved night vision under starlight illumination, and high-speed, radiation hard, ultra-low power analog and digital circuits for ubiquitous DoD applications.

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(U) Project Number and Title: P534 Lincoln Laboratory

(U) <u>PROGRAM ACCOMPLISHMENTS AND PLANS</u>

(U) <u>FY1999 Accomplishments:</u>

(U) **<u>Target Surveillance and Recognition</u>** :
(U) <u>Surface Surveillance</u>
(U) Developed preliminary design for new multichannel airborne data collection system emphasizing advanced, EECM-capable GMTI as well as SAR. Applied fundamental target-recognition bounds to comparative study of moving and stationary target recognition. Initiated investigation of active seismic characterization of underground facilities. Applied computational models, conducted scale model measurements and preliminary field tests, and initiated development of sparse-array processing techniques. In addition to being directly applicable to ongoing R&D efforts such as DARPA`s MTE, MSTAR and underground-facilities programs, these activities will have considerable significance for organizations, such as NIMA, NRO and the Services, that are planning and/or developing next-generation sensing and exploitation systems.
(U) <u>Space Surveillance</u>
(U) Continued the advanced electro-optical technology program in support of the Air Force Space Control Mission. This included the development of an avalanche photo-diode (APD) array for 3-D laser radar imaging for applications such as terminal guidance on BMD interceptor and tactical seekers. Timing circuits, which will ultimately be bonded to the APD arrays, have been fabricated and tested. The epoxy-bonding and etching technology has been demonstrated. A 3-D laser radar brassboard system has been used to collect image data for aimpoint-selection and discrimination algorithm development. Continued the development of CMOS readout test structures for IR focal plane arrays towards the goal of developing readout multiplexers for IR focal-plane arrays that will incorporate silicon-on-insulator fabrication processes and on-chip signal processing. Tested binary-optics-grating technologies for enabling simultaneous multi-wavelength detection with a single focal plane. These focal-plane-array technologies have the common application of advanced BMD seekers.

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(**U) Sonar Target Classification**
Initiated the development of a sonar signal processing laboratory that provides the capability for near-real-time processing of hydrophone array data from submarine towed array systems, from beamforming through automatic classification and operator displays. Initiated development and testing of the Interactively-trainable Passive Acoustic Classifier (IPAC). Developed and demonstrated adaptive matched field processing for depth-based discrimination of surface noise from submerged targets. Developed and demonstrated approaches for mitigating a form of ownship noise called cable strum that can obsure important signatures in the forward endfire direction.($ 4.977 Million)
(U) **Military Communications** :
(U) Continue to investigate technology for global high-rate military communications and networking at rates from tens of megabits to tens of gigabits per second, including optical communications and tactical theater communications (particularly to Army forces on the move).
(U)Optical Communications: Completed free-space optical communications technology transition to the funded flight demonstration program. Continued work to enhance optical transmitter power and efficiency as well as near-quantum-limited optical receiver technology. Application to world-wide relay of high-rate surveillance data.
(U)Global Ultra-high-rate Networks: Continued development of optical technology for ultra-high-rate local and metropolitan area networks (LANs and MANs), with application to processing and fusion of surveillance data. Demonstrated 100 Gbps logic gate, clock recovery, and transmission for an ultra-fast, single-stream soliton network. Initiated test-bed demonstration of the 100 Gbps LAN and MAN utilizing soliton optical pulses and optical processing (current state-of-the-art for electronic networks is ~2 Gbps). Provided preliminary solutions to problems of transient effects in optical amplifiers and dispersion in cascaded optical filters. Developed algorithms to leverage unique advantages of optical networks and facilitate dynamic bandwidth allocation and interconnection of disparate military communication systems.
(U)Milsatcom: Completed architecture study for EHF Milsatcom beyond 2005, using agile and narrow RF beam steering, advanced low-power on-board signal processing, and new networking techniques to enable efficient computer communications over EHF Milsatcom. Continued development of electromagnetically-steered phased array antennas utilizing optical fiber and electro-optical technologies that offer light-weight, low-cost fabrication and integration on tactical platforms. Completed implementation of an 8 GHz receive array. Application to ground forces communication on the move, to aircraft, and to radars.
(U)Defensive Information Warfare: Coordinate first-ever quantitative evaluation of computer network intrusion detection (ID) software performance. Found existing GOTS systems performed worse than new development ID systems, but both are poor in detecting novel, first-seen attacks. Developed better background traffic simulations and stealthier attacks for the second annual ID evaluation. Extended unique LL Bottleneck Verification ID system and began testing on real traffic at Hanscom Air Force Base. Developed and demonstrated self-deploying ID protocols to respond dynamically to attacks.
($ 4.183 Million)

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(U)Combat Support Technology:
(U)Designed and developed a baseline active hyperspectral imaging (HSI) system that incorporates VIS/NIR white-light `laser` illuminator on a scanning, tripod-mountable platform with compact imaging spectrometers. The system was successfully tested in a series of laboratory experiments to demonstrate utility in detection and identification of concealed targets in a low-light, highly-cluttered environment. A series of outdoor tests designed to verify performance in concealed target detection and demonstrate range-gating ability were also conducted. Applications for the baseline system include mine detection, optical taggant discrimination and man or vehicle vision enhancement.
(U)A large number of field measurements of background clutter were made with the Biological Aerosol Warning Sensor (BAW-III), an UV fluorescence sensor. Measurements this past year concentrated on urban environments, including Atlanta, Boston, Cambridge MA, and Washington DC. These measurements are being used to calculate probability-of-detection versus false-alarm rates for the sensor. Based on the measured performance of the BAWS-III the Joint Program Office for Biological Defense (JPO BD) has selected the BAWS-III for insertion into the Joint Biological Point Detection System (JBPDS) beginning in late FY99. To further improve the performance of the BAWS-III sensor, advanced laser work was initiated to reduce the power requirement, which is important for hand-held sensor applications. A new protocol was developed detecting trace amounts of biological substances in large volumes of soil; the protocol was successfully demonstrated in the laboratory using a wide variety of soil types. Based on this work a new program has been initiated in measuring contaminated soils for suspect biological particles. Microfluidics work continued with the focus on developing concepts for compact cartridges to do DNA/RNA extractions from soil samples. In the simulation area, a model of the BAWS-III sensor was incorporated in the ModSAF simulator package.
($ 4.106 Million)
(U)Advanced Electronics Technology:
(U)The general objective of this program is to conceive, demonstrate, and provide advanced electronic devices, circuits and subsystems for Air Force and other DoD systems, and to transfer enabling technologies to industry. Principle efforts are in lasers, electro-optic devices, visible and infrared (IR) sensor arrays, analog and digital silicon integrated circuits, microwave and terahertz devices, biochemical sensors, and superconducting electronic devices, along with supporting development of materials and processing techniques. These efforts support DoD systems programs elsewhere within Lincoln Laboratory, as well as directly supporting AFRL (IR countermeasures (CM), adaptive optics, focal-plane readout circuits, electro-optical space surveillance, power-combined solid-state lasers). Technology from this program is exploited by the Army and Navy ballistic missile defense programs (focal-plane readout circuits), by Army SBCCOM (bioaerosol sensors), by DARPA (sub-0.25-µm lithography, low-power/high-speed CMOS integrated circuits (IC) in silicon-on-insulator (SOI) material, high-speed optical sampling for analog-to-digital (A/D) conversion, microfluidic bio-agent identifier, multichip modules, microelectromechnical (MEM) reconfigurable microwave circuits and antennas, tunable superconductive filters for agile receivers), and by NSA (superconductive crossbar switch, high-speed cryogenic memory). Technology transfer is being accomplished through direct DoD support (IR countermeasures, CMOS/SOI circuits, imaging arrays and readout circuits, bioaerosol sensors), and through cooperative research development agreements (CRDAs) (microchip UV lasers, lithographic technology, and diamond switch technology).

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(U) Selected accomplishments: Developed and integrated high-power, high brightness lasers at 2- and 4-µm for dual-band IRCM into demonstration subsystem with industry; Demonstrated optically sampled A/D converter at above 200 Msamples/s with 10-bit resolution and third-order intermodulation distortion below -80dB; Demonstrated first CCD imagers and CMOS/SOI logic with a unique merged CMOS/CCD technology for `smart` focal planes; Developed superconductive chirp filters with very low (-45 dB) error sidelobes and thereby enabled the demonstration of a 4-GHz-bandwidth compressive receiver with high dynamic range for electronic intelligence (ELINT); Fabricated several additional IC designs (now 92 in total) in the CMOS/SOI 0.25-µm technology, with a direct comparison showing up to 40 times lower power at 1-GHz speed than commercial GaAs; Demonstrated new concept for wavelength-power-combining of laser sources with broad applications to high-brightness DoD systems; Performed key experiments and analysis which led to semiconductor industry decision to develop 157-nm wavelength optical lithography for sub-100-nm IC fabrication.
($ 6.953 Million)

(U) FY2000 Plans:

(U) Target Surveillance and Recognition:
(U)Surface Surveillance:
(U) Extend fundamental target-recognition bounds to multi-look, multi-frequency and polarimetric sensing. Initiate formulation and analysis of multi-sensor concepts for high-performance, resource-efficient wide-area battlefield target recognition. Continue theoretical and experimental investigation of sparse-array techniques for active seismic imaging of underground facilities. In addition to being directly applicable to ongoing R&D efforts such as DARPA`s MTE, MSTAR and underground-facilities programs, these activities will have considerable significance for organizations, such as NIMA, NRO and the Services, that are planning and developing next-generation sensing and exploitation systems.
(U)Space Surveillance
(U)Continue 3-D laser radar technology development with the final hybridization of 32 x 32 avalanche photo-diode (APD) arrays with arrays of CMOS timing electronics. These arrays will be incorporated into the brassboard system for the demonstration of single-photon-sensitivity 3-D imaging for advanced BMD and tactical seekers. Begin the development of APD arrays, which are sensitive at 1.5-micron wavelengths, for use with eyesafe laser transmitters. This will include the development of single-element and small arrays of diffusion-bonded structures utilizing an InGaAs absorption region and a silicon avalanche region. These APD arrays will be compatible with the co-developed CMOS timing circuitry and will enable 3-D laser radar systems for use in combat-identification and vehicle-navigation applications as well as tactical seekers in urban environments where laser eyesafety is a requirement. Begin the development of a laser-transmitter system that incorporates the multi-functional capability of 3-D laser radar and laser-vibration sensing. This system would incorporate APD arrays for the 3-D imaging along with a long-coherence-time mode-locked laser transmitter, which would allow coherent detection for vibration measurements and has applications in combat identification.

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(U) <u>Sonar Target Classification</u>
Continue to investigate the benefit of improved front end beamforming techniques but focus more on the impact of improved features on classifier and overall system performance. Explore and demonstrate adaptive techniques for array calibration to improve sonar performance during ownship maneuvers. Strong interfering surface ships can serve as sources of opportunity that can be used to automatically calibrate or estimate array shape. The estimated shape will then be used directly within the beamformer to improve target SNR.
($ 4.787 Million)
(U)<u>Military Communications</u>:
(U) Continue to investigate technology for global high-rate military communications and networking at rates from tens of megabits to tens of gigabits per second, including optical communications and tactical theater communications (particularly to Army forces on the move). Global ultra-high-rate networking: Initial implementation of ultra-high-rate optical network from Lincoln Laboratory to Washington, DC under funded programs; will be available for demonstrations of line-funded fiber optic communications techniques. Demonstrate 100 Gbps packet assembly, transmission and reception over optical fiber in laboratory testbed. Develop novel applications using high-speed optical backbones such as cooperative processing of radar data and other applications. Tactical Satellite Terminals: Complete transfer of technology of optically controlled phased array antennas into funded radar and communication programs.
(U)Defensive Information Warfare: Bottleneck Verification System will be further refined and evaluated, then will be extended beyond looking for illegal user-to-root transitions to other attack classes and mechanisms. This technology will be transferred to AFWIC for deployment over a wide range of Air Force base computer networks. The set of information assurance components in the yearly product evaluation will be extended to encompass protection (e.g. firewalls) and reaction (e.g. security service desks) subsystems in addition to ID subsystems. Begin development of systems that can identify and not merely detect intrusion attacks.
($ 3.656 Million)
(U) <u>Combat Support Technology</u>:
(U)Active Hyperspectral Sensing Systems: Extend the operating spectral region of both the white light `laser` and the spectral imaging systems from VIS/NIR to encompass 3 to 5 micron bands. Continue processing algorithm development in order to identify key features for target recognition and visualization using the extended sensing capability. This system will continue to be tested in both laboratory and field environments on a variety of targets and scenarios of military interest. Design of a full-spectral system, spanning the visible through infrared bands will be initiated and the factors affecting fusion with other sensing systems, such as synthetic-aperture radar and other EO sensors, will be examined.

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(U)Biological Agent Detection Systems: The work will begin to focus on a miniature, low-power sensor incorporating a UV fluorescence sensor at the front end, a B-cell-based identifying sensor at the back end, and stages of intelligent particle sampling and sample purification in the middle. For the UV sensor, work will continue on reducing the laser power requirements, and work will begin on aggressively miniaturizing the sensor. Development will begin on a fully intelligent, integrated particle sampler and on the microfluidic sample-purification sub-system. Modeling and sisimulation efforts will continue with emphasis on how the integrated sensor would perform in urban environments. In addition, work will continue on cartridge-based soil measurements and on background measurements. These technology efforts will flow into the Joint Biological Point Detection System (JBPDS) and into the Joint Biological Remote Early Warning System (JBREWS) ACTD.
($ 4.536 Million)

(U)<u>Advanced Electronics Technology</u>:

Extend direct RF optical sampling to bandwidths beyond 100 MHz by demonstrating scalable methods for parallelizing quantizers: Begin system demonstration of utility of optical sampling for digital receivers at radar field site. Improve materials and spectral combining techniques enabling higher-brightness and higher-operating-temperature optically pumped mid-IR semiconductor lasers for IRCM applications. Reduce dark current levels and develop CMOS-based versions of visible, UV and IR focal planes in support of AF, DARPA, and other DoD programs. Continue development of advanced silicon process technology with extensions of CMOS to sub-100-nm feature sizes, with emphasis on development of technologies for on-focal-plane processing, radiation-hard technologies, and integrated sensors. Continue development of tunable superconductive RF filters for frequency-agile receivers. Demonstrate 4-GHz bandwidth ELINT receiver incorporating superconductive chirp filters and CMOS/SOI data processor. Continue development of bio-detector technology based on integration of living biological cells with microfluids and microelectronics with emphasis on discrimination and identification methodologies. Demonstrate 3-D radar subsystem incorporating a 32x32 array of geiger-mode avalanche photodiodes (APD), integrated timing electronics, and compact laser illuminator. Demonstrate APD arrays for use at eye-safe wavelengths applications. Demonstrate microelectromechanical (MEM) RF tuning structures for electronically reconfigurable microwave receivers and antennas. Initiate development of AlGaN UV detectors for solar- blind applications.($ 7.21 Million)

(U) <u>FY2001 Plans:</u>

(U)<u>Target Surveillance and Recognition</u>:

(U)<u>Surface Surveillance</u>:

(U)Develop and apply absolute (vs. relative, between two sensor designs) fundamental ATR performance bounds. Apply multi-sensor ATR concepts to development of practical multi-sensor ATR architectures for high-performance, resource-efficient, wide-area battlefield target recognition. Design field experiments to demonstrate such architectures. Refine techniques for sparse-array active seismic imaging and demonstrate an existing underground facility. In addition to being directly applicable to ongoing R&FD efforts such as DARPA`s MTE and MSTAR programs, these activities will have considerable significance for organizations, such as NIMA, NRO and the Services, that are planning and developing next-generation sensing and exploitation systems.

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(U)Space Surveillance:
(U)Continue 3-D laser radar technology development with the scaling of the array sizes to greater than 32 x 32 pixels. These larger arrays will have applications for advanced BMD and tactical seekers and ground mapping and foliage penetration. Continue the development of 1.5-micron-sensitive APD arrays with the scaling of the single-element and small arrays to 32 x 32, or larger, array sizes. These devices will enable the single-photon-sensitive 3-D laser radar technologies to be used in the eyesafe regime for applications such as combat identification and tactical seeker homing in urban environments. Continue the development of multi-function laser transmitters, which are capable of 3-D imaging and laser-vibration sensing, for applications of combat identification and underground-structure sensing.

(U)Sonar Target Classification
Expand application of IPAC classification approach beyond submarine towed array sonars to the fixed (SOSUS) and mobile (SURTASS) surveillance problems. Develop techniques for operator in-situ training and test with field data. Develop dynamic databases to permit sonar to exploit knowledge of environment, intelligence information, external sensor data on surface ship clutter.($ 4.078 Million)

(U)Military Communications:
(U)Continue to develop technology for global high-rate military communications and networking, including optical communications in space and fiber. Continue demonstration and extension of networking techniques and protocols for interworking among disparate networks including Milsatcom. Complete testing of ultra-fast optical testbed with 100 Gbps transmissions between Lincoln Laboratory and Washington, DC (application to surveillance data processing). Investigate novel application areas for optical technology such as ultra-fast data encryption and processing.
(U) Defensive Information Warfare: Development and evaluation of advanced techniques for network intrusion detection will continue. Focus will shift towards detection of insider attacks (i.e. attacks from users who have authorized access to the system). Build systems that process complementary data from an ensemble of cooperating intrusion detection systems, for improved aggregate performance. Develop systems that can determine an attacker`s intent.($ 3.449 Million)

(U) Combat Support Technology:
(U) Active Hyperspectral Sensing System: Develop a full-spectral active HSI system, using select, discrete-frequency laser wavelengths throughout the visible through mid-wave IR spectral regions, broadband illumination in discreet segments of those regions, and passive long-wave IR imaging. The system will be adaptable, where both the sensing wavebands and target-recognition algorithms will be specified by the applications. For some applications, visible APD arrays will be incorporated that permit range-resolved imaging as well as the standard spatial and spectral imaging that the active HSI system affords. Effort will also be expended in developing real-time processing and visualization schemes for either direct relay to user or transmission to a control station for fusion of multiple sensing assets.
(U)Begin to explore how to adapt B-cell-based sensor for integrated package. This technology development may feed into an integrated, miniature low-power sensor at a later date.($ 2.014 Million)

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(U) Advanced Electronics Technology:
(U) Investigate highly scaled CMOS/SOI digital circuits using mixed electron-beam and optical lithography at 25-nm feature sizes for ultradense circuits. Explore integration of ICs in the third dimension as a means to significantly improve functional density. Demonstrate compact and power efficient version of optically sampled A/D with multi-GHz bandwidth for radar and electronic intelligence use. Extend highly integrated CCD/CMOS imager to include noiseless jitter compensation of platform motion. Continue development of UV, visible, IR and hyperspectral imaging devices with on-focal-plane processing for `smart` multimode sensors. Transfer advanced mid-IR semiconductor laser technology to industry for dual-wavelength IRCM. Continue development of combined biochemical, micromechanical, electronic systems. Continue development of solid-state devices, materials and processing subsystems in support of DoD programs.
($ 5.335 Million)

(U) B. Program Change Summary	FY1999	FY2000	FY2001	Total Cost
Previous President's Budget	19.271	20.774	20.739	Continuing
Appropriated Value	0.000	0.000	0.000	Continuing
Adjustments to Appropriated Value				
a. Congressionally Directed Undistributed Reduction	0.000	0.000	0.000	
b. Rescission/Below-threshold Reprogramming, Inflation Adjustment	(.948)	(.070)	(.137)	
c. Other	0.000	(.515)	(2.000)	
Current President's Budget	20.219	20.189	18.602	Continuing

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Change Summary Explanation:

(U) **Funding:** FY 2000 adjustments were the result of inflation adjustments and the government wide rescission. FY 2001 reflects inflation savings.

(U) **Schedule:** N/A

(U) **Technical:**

(U) **C.** **OTHER PROGRAM FUNDING SUMMARY COST:** N/A

(U) **D.** **ACQUISITION STRATEGY:** N/A

(U) **E.** **SCHEDULE PROFILE:** N/A